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### Intelligent load management in microgrids

J Kennedy  
*University of Wollongong*

Philip Ciufo  
*University of Wollongong, [ciufo@uow.edu.au](mailto:ciufo@uow.edu.au)*

Ashish Agalgaonkar  
*University of Wollongong, [ashish@uow.edu.au](mailto:ashish@uow.edu.au)*

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## Intelligent load management in microgrids

### Abstract

The increased levels of distributed generator (DG) penetration and the customer demand for high levels of reliability have attributed to the formation of the Microgrid concept. The Microgrid concept contains a variety of technical challenges, including load management and anti-islanding protection discrimination strategies. This paper provides a novel scheme in which loads and DG are able to detect the conditions where the load of the island cannot be sufficiently supplied. In these instances, a load shedding algorithm systematically removes loads from the system until an island can be maintained within satisfactory operating limits utilising the local DG. The concept of an Intelligent Load Shedder (ILS) module is proposed in this paper. This module is connected in series with non-critical loads in order to detect the conditions where that non-essential load should be isolated from an island. This module must be capable of communicating with the static transfer switch (STS), which is the intelligent isolator associated with the island. The STS will also be capable of sending and receiving data with each DG's islanding protection device. The combined algorithmic control of the STS, ILS module and DG islanding protection device forms the Intelligent Load Management algorithm. This algorithm is capable of islanding protection and load shedding irrespective of the use of communications. The algorithms within this paper are simulated using MATLAB script. The results show that, on a theoretical level, the intelligent load management scheme described in this paper can be used to detect the conditions where an insufficient load is available using local parameters. Load shedding coordination is also shown to be possible with and without the use of communications between the STS, ILS module and DG islanding protection module.

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# Intelligent Load Management in Microgrids

J. Kennedy, P. Ciufo, A. Agalgaonkar

School of Electrical, Computer and Telecommunications Engineering

University of Wollongong

Wollongong, NSW Australia

jtk847@uowmail.edu.au

**Abstract**—The increased levels of distributed generator (DG) penetration and the customer demand for high levels of reliability have attributed to the formation of the Microgrid concept. The Microgrid concept contains a variety of technical challenges, including load management and anti-islanding protection discrimination strategies. This paper provides a novel scheme in which loads and DG are able to detect the conditions where the load of the island cannot be sufficiently supplied. In these instances, a load shedding algorithm systematically removes loads from the system until an island can be maintained within satisfactory operating limits utilising the local DG. The concept of an Intelligent Load Shedder (ILS) module is proposed in this paper. This module is connected in series with non-critical loads in order to detect the conditions where that non-essential load should be isolated from an island. This module must be capable of communicating with the static transfer switch (STS), which is the intelligent isolator associated with the island. The STS will also be capable of sending and receiving data with each DG's islanding protection device. The combined algorithmic control of the STS, ILS module and DG islanding protection device forms the Intelligent Load Management algorithm. This algorithm is capable of islanding protection and load shedding irrespective of the use of communications. The algorithms within this paper are simulated using MATLAB script. The results show that, on a theoretical level, the intelligent load management scheme described in this paper can be used to detect the conditions where an insufficient load is available using local parameters. Load shedding coordination is also shown to be possible with and without the use of communications between the STS, ILS module and DG islanding protection module.

and power quality [4].

This paper presents a novel load management scheme utilising load shedding and DG islanding protection techniques. Load shedding can be defined as the amount of load required to be disconnected from a system to keep that system within satisfactory operational limits [5]. Load shedding algorithms are essential within the scope of the Microgrid concept, as it is unreasonable to assume that there will always be sufficient generation available to supply the load within an island [6]. The concept of an Intelligent Load Shedder (ILS) module is introduced in this paper, in which measurement devices, a microcontroller and a circuit breaker are combined and connected in series with non-critical loads. An ILS module is capable of making load shedding decisions based on local measurements and a knowledge of the aggregate load in an island. Anti-islanding protection is also required within the Microgrid concept to account for instances where the load within an island exceeds the total DG power capability after load shedding has taken place. Voltage and/or frequency shift will occur after the formation of an island if either real or reactive power absorbed or injected into the microgrid was non-zero prior to the formation of the island. It is essential to employ the design premise that no islanding detection method is 100% effective [7] and the effects of non-detection should be considered.

## I. INTRODUCTION

The proliferation of distributed generation (DG) in subtransmission and distribution networks can be attributed to various government-driven economic incentives formulated in an effort to stem the flow of carbon emissions into the atmosphere. With the looming implementation of a carbon tax regime in Australia, it is reasonable to assume that renewable energy resources will continue to be a very attractive investment for industrial and commercial proprietors. Concurrently, power utility companies have been subjected to increased demands for reliability of supply to customers [1], [2]. A seemingly natural solution to meeting the public demand for reliability and maximising the use of DG is the Microgrid concept [3], where decentralised energy resources are used to supply local customers in the absence of mains connection. However, the Microgrid concept contains a series of technical issues concerned with protection, control

DG can be broadly classified as dispatchable, such as fuel cells with short term storage and combustion engines, or non-dispatchable, such as solar photovoltaic or wind. Dispatchable DG units are considered to be extremely reliable and flexible in operation, whereas non-dispatchable DG units require a significant amount of long term storage to be considered reliable due to the lack of availability of renewable energy resources [2]. Each DG unit must be capable of detecting the conditions under which a control scheme change is necessary due to the formation of an island or reconnection to the mains. Separate control strategies are required for dispatchable DG units for autonomous and grid-connected modes of operation. Small-scale non-dispatchable DG units may or may not require an autonomous mode of operation, depending upon the presence of large dispatchable generators within the Microgrid. The extra cost of the control and protection equipment required for autonomous control of a DG unit may not justify maintaining connection of a small-scale, renewable

DG unit which has a limited power supply and availability. A strong Microgrid containing dispatchable DG should be able to emulate a mains connection from the perspective of a small-scale renewable DG unit.

The authors of [8] propose a load shedding algorithm for a constant resistive load in a Microgrid. A  $\frac{dV}{dt}$  method was used to determine the necessary amount of load to be shed within the decision making process. This method does not take into account the islanding response of inductive or capacitive loads where a voltage deviation will not detect any problems concerning the reactive power capabilities of a DG unit.

A hard-wired or communications based inter-trip load shedding scheme could be used in order to trip excess loads instantaneously when a static transfer switch (STS) opens to form a Microgrid or when a DG is lost. This inter-trip load shedding scheme would be designed under the premise of a worst case loading scenario. However, as [5] mentions, this process may lead to many unnecessary disconnections and load priorities are difficult to enforce. Transmission level load shedding methodologies often use either frequency response or a combination of frequency and load data acquisition in decision making processing [5]. Frequency response is typically slow where synchronous machines are present as they contain a significant amount of inertia. Load data acquisition is very useful where a comprehensive monitoring system is available on the network. However, communications systems cannot be considered 100% reliable, and distribution system data may not always be as readily accessible as in transmission networks.

This paper presents an Intelligent Load Shedding device which shall be installed at the point of common coupling (PCC) of any low-priority loads of significant size. Financial remuneration or penalties may be necessary such that a customer may elect to be considered a low-priority load. A combination of a communications link with the STS and passive voltage/frequency detection allows an effective load shedding technique with contingency planning for when communications systems fail.

This paper is organised as follows: Section II contains the theory and algorithmic control of the complete Intelligent Load Management Algorithm. Section III presents several simulations verifying the effectiveness of the Load Management Algorithm for different loading scenarios. The contingency plans for communications failure are also explored. The conclusions for this paper are given in section IV.

## II. LOAD MANAGEMENT ALGORITHMS

### A. DG Islanding Protection

Fig. 1 presents an equivalent circuit of a single DG unit connected to an island. A resistive, inductive and capacitive element are all connected in parallel to clearly separate the

real, inductive and capacitive power components of the island. The DG unit is assumed to operate as a line-commutated, constant power source prior to island detection. Constant power control is very common in grid interfaced DG units as this mode is simple and maximises the revenue generated from a DG. Each load is assumed to be linear; i.e. not frequency nor voltage dependent. This equivalent circuit is highly analogous of the Thévenin equivalent circuit and greatly simplifies the subsequent calculation procedures for the steady state frequency and voltage shift of a DG.

Fig. 1. Equivalent circuit of an island

If a real power imbalance is present in the island, a DG unit will vary the voltage in order to achieve the real power set-point within the DG unit's control scheme. The resultant voltage magnitude  $|V_{DG}|$  at the terminals of the DG can be determined by:

$$|V_{DG}| = \sqrt{\frac{P_{sp}}{P_{rated}}} \quad (1)$$

Where  $P_{sp}$  is the real power set point of the DG unit's control scheme and  $P_{rated}$  is the rated absorbed real power of the island. The angular frequency  $\omega$  of the island can be determined by:

$$\omega = \frac{-Q_{sp} + \sqrt{Q_{sp}^2 + 4Q_{c_{rated}}|V_{DG}|^4Q_{l_{rated}}}}{2Q_{c_{rated}}|V_{DG}|^2} \quad (2)$$

Where  $Q_{sp}$  is the reactive power set point of the DG's control scheme,  $Q_{l_{rated}}$  is the rated reactive power of the equivalent island inductance and  $Q_{c_{rated}}$  is the rated reactive power of the equivalent island capacitance. From (1) and (2), a systematic approach towards the discrimination between the requirements for autonomous operation and anti-islanding protection can be derived.

Fig. 2 contains a flow chart which explains the decision making process of the islanding protection for a DG unit. The islanding protection system will require a phase locked loop to determine the system frequency and a voltmeter to determine the voltage at the PCC, both of which are already incorporated in a contemporary anti-islanding protection scheme of a DG unit. The islanding protection scheme shall also require a knowledge of the  $P - Q$  capabilities of the DG

in the form of a look up-table.

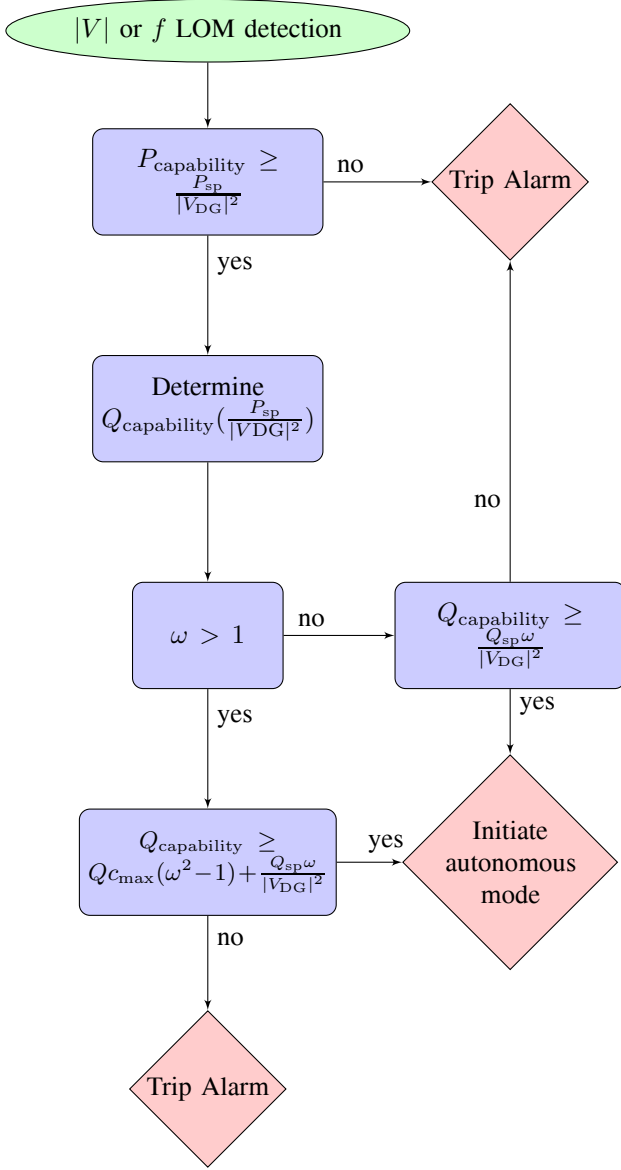


Fig. 2. DG Islanding Protection Flowchart

Firstly, under/over voltage protection (U/OVP) and under/over frequency protection (U/OFP) shall be required to detect loss of mains (LOM) when a sufficient frequency or voltage deviation has occurred to trigger the islanding protection algorithm. If an island is formed and the complex power deviation is insufficient to trip either U/OVP or U/OFP, an acceptable condition has arisen as the islanding protection bounds should reflect the acceptable frequency and voltage of that island. Secondly, from (4), a decision can be made as to whether the real power capabilities  $P_{\text{capability}}$  of the DG can sufficiently meet the load. A look-up table is used to approximate the maximum reactive power capability  $Q_{\text{capability}}$  of the DG using the calculated power absorbed by the equivalent resistive load of the island  $P_{\text{rated}}$  (see equation

(5)).

$$P_{\text{capability}} \geq P_{\text{rated}} \quad (3)$$

Hence from (1):

$$P_{\text{capability}} \geq \frac{P_{\text{sp}}}{|V_{\text{DG}}|^2} \quad (4)$$

$$Q_{\text{capability}}(P_{\text{rated}}) = Q\left(\frac{P_{\text{sp}}}{|V_{\text{DG}}|^2}\right) \quad (5)$$

If the angular frequency  $\omega > 1$ , an estimation of the largest possible island capacitance  $Q_{c_{\text{max}}}$  must be used in order to determine whether a DG unit shall be able to provide reactive support to the island.  $Q_{c_{\text{max}}}$  is used rather than  $Q_{l_{\text{max}}}$  as the capacitive load of an island is subject to less variation than inductive load.  $Q_{c_{\text{max}}}$  value will need to be pre-defined in each islanding protection system and should represent the equivalent maximum capacitance of the island incorporating factors such as cabling type and the presence of capacitor banks. Rearranging equation (2):

$$Q_{c_{\text{rated}}}|V_{\text{DG}}|^2\omega^2 + Q_{\text{sp}}\omega = |V_{\text{DG}}|^2Q_{l_{\text{rated}}} \quad (6)$$

It is required that:

$$Q_{\text{capability}} \geq Q_l - Q_c \quad (7)$$

Hence:

$$Q_{\text{capability}} \geq Q_c(\omega^2 - 1) + \frac{Q_{\text{sp}}\omega}{|V|^2} \quad (8)$$

$Q_c \in \mathbb{R}^+$ . Hence, if  $\omega < 1$ , (7) can be satisfied if:

$$Q_{\text{capability}} \geq \frac{Q_{\text{sp}}\omega}{|V_{\text{DG}}|^2} \quad (9)$$

Upon completion of this algorithm, a DG unit shall be able to discriminate between the need to change to autonomous control or the need to isolate itself by analysing the parameters measured at the PCC. An additional advantage of this algorithm which may be employed is an improved response to an over-voltage occurring during grid-connected mode. The islanding protection associated with the DG unit can communicate with the STS to ascertain that the DG unit is in grid connected mode and either trip the DG or lower the  $P_{\text{sp}}$ .

### B. Load Shedding Algorithm

A feeder often contains loads which may be considered to have varying priorities. Financial incentives or penalties may be necessary in order to allow customers to elect to be considered a lower priority once an island has occurred. Connection to non-critical loads may be sacrificed in order to maintain supply to higher priority loads. The linear load, shown in Fig. 3, is connected through an Intelligent Load Shedding (ILS) module. This controller can determine the conditions under which the DG supply within the island is insufficient using only locally gathered data. Similarly to the DG islanding program, the frequency and voltage at the PCC are the quantitative parameters implemented in the decision

making process of the algorithm of the ILS module.

Fig. 3. Intelligent Load Shedding

In steady state, the island frequency is constant across the feeder. However, the voltage profile is subject to voltage drop, which is dependent on the line impedance, real-time load characteristics, feeder topology, DG presence and DG control. These parameters are not predefined or made available the microprocessor of the ILS.

By (1), the voltage at the terminals of the DG shall decrease if the rated real load of the island is greater than the real power set point of the DG unit. Hence, if the voltage of the load detects a significant under-voltage using UVP, the real power support of the DG is considered by the ILS module to be incapable of feeding the entire load of the feeder.

In order to determine whether the reactive capabilities of the DG in the island are sufficient, an approximation of the maximum total rated real  $P_{ILS}$  and inductive  $Q_{ILS}$  load of the island at the time of each ILS trip condition is required. This approximation is determined by combining the maximum predicted rated real and inductive load of the island after all lower priority ILS modules have isolated.

$$Q_{ILS_k} = Q_{l_{island}} - \sum_{n=1}^{k-1} Q_{l_{triplist(n)}} \quad (10)$$

$$P_{ILS_k} = P_{island} - \sum_{n=1}^{k-1} P_{triplist(n)} \quad (11)$$

Where  $P_{island}$  and  $Q_{l_{island}}$  are the total real and inductive loads of the island respectively.  $Q_{l_{triplist}}$  and  $P_{triplist}$  are the respective rated real and reactive loads connected to the ILS defined in triplist. The inductive load of the island is chosen as a higher deviation of inductive power rather than capacitive power tends to occur when a load is lost. Hence, nuisance tripping of ILS modules is less likely to occur.

A look-up table is used by the ILS to predict the maximum reactive power capability of the local DG aggregate. The maximum reactive power capability  $Q_{capability}$  is a function of the maximum power output of the DG  $P_{capability}$ . A DG in grid connected mode usually operates at full load near unity power factor at maximum load, hence:

$$P_{sp} \approx P_{capability} \quad (12)$$

$$|V_{DG}| = \sqrt{\frac{P_{sp}}{P_{rated}}} \quad (13)$$

Assuming a voltage drop across the island, which is common if load shedding is necessary:

$$|V_{DG}| \geq |V_{ILS}| \quad (14)$$

$$P_{capability} = |V_{ILS}|^2 P_{ILS} \quad (15)$$

Where  $|V_{ILS}|$  is the magnitude of the voltage at the ILS. In order to determine that the reactive power support in the island is satisfactory, equation (16) must be satisfied.

$$Q_{capability}(|V_{ILS}|^2 P_{ILS_k}) > Q_{ILS}(i - \frac{1}{\omega^2}) + \frac{Q_{sp}}{|V_{ILS}|^2 \omega} \quad (16)$$

If the reactive power set point  $Q_{sp}$  is zero or inductive, (16) can be reduced to (17).

$$Q_{capability}(|V_{ILS}|^2 P_{ILS_k}) \geq Q_{ILS}(1 - \frac{1}{\omega^2}) \quad (17)$$

Otherwise, an approximation for the capacitive reactive power set point  $Q_{sp}$  must be known. Presently, grid-connected DG mostly operates using constant power control close to unity power factor. Hence, a knowledge of  $Q_{sp}$  will only be necessary with an amendment to grid-connected DG control design philosophy to allow for a significant reactive power support of the network.

The flow chart shown in Fig. 4 portrays an algorithmic approach towards detecting the required amount of load shedding in order to maintain adequate supply to the bulk of an island. This algorithm can be considered unnecessary where healthy communication links are available between DGs, STSs and ILSs since the required load shedding can be done systematically using DG PCC data. If an extra DG is added to the network, it may be possible that the isolated load be reconnected if the available load of the DG aggregate can supply the non-critical load. Communications will be necessary between ILS and STS in order to determine when mains has been reconnected and the load should be reconnected to the grid.

The capture and delay block is included to allow for load shedding discrimination between ILS modules without communications. The lowest priority ILS has the shortest delay. When an ILS is tripped, a small delay is incorporated to allow the system to stabilise prior to next highest priority ILS module trip sequence. The time dial selections of each ILS will have to incorporate delays in CB operation and processing time and is likely to take marginally longer than tripping by STS 'trip list'.

### C. Coordination of DG Islanding Protection and Load Shedding Algorithm

An intentional island is typically formed through isolation of a section of the grid with high DG penetration by an STS [9]. A voltage and frequency shift will most likely occur in response to the shift in power demand drawn from the constant power sources. If the complex power deviation is insufficient

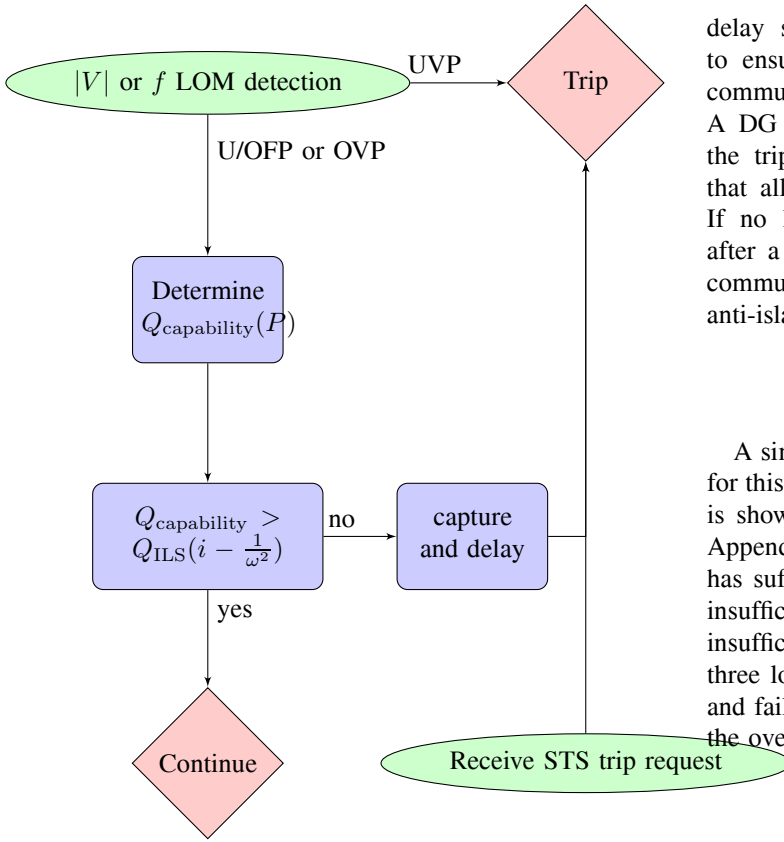


Fig. 4. Intelligent Load Shedding Flowchart

to be detected by islanding protection methodologies, the DG will continue to sustain voltage and frequency within limits and operate as expected using power control mode. However, if the voltage or frequency shift exceeds threshold values, either load shedding or anti-islanding protection are necessary to protect the island. This paper proposes a load management algorithm which maximises the use of DG whilst maintaining voltage and frequency parameters within the island.

All DG units within an island must wait until all load shedding possibilities are attempted prior to the activation of anti-islanding protection. Hence, initially only an anti-islanding alarm is activated by the islanding protection upon detection of insufficient DG supply for the island. This warning is sent to the STS which subsequently initiates load shedding algorithms. Load shedding time can be minimised if the STS directs each ILS to trip sequentially in order of lowest to highest priority. An ILS priority arrangement or ‘trip list’ defines the order of importance of each load connected through an ILS. A delay is incorporated between ILS isolation instructions in order to allow the system dynamics to stabilise such that the STS can observe if the anti-islanding protection alarm has stopped. This delay must take into consideration the types of DG units present in the system as synchronous machines require more time than static interfaced DG units to reach stability due to their inherent inertia. Different time

delay settings shall be required within each ILS module to ensure load shedding discrimination is possible with a communications failure between the STS and ILS module. A DG unit’s islanding protection algorithm shall wait after the trip alarm has been sent to be informed by the STS that all load shedding methodologies have been attempted. If no load shedding completion signal has been received after a prescribed time limit, the DG unit will assume that communications have failed and time out, activating the anti-islanding protection.

### III. SIMULATIONS

A simulation platform of a simple island has been designed for this paper using MATLAB script. The island configuration is shown in Fig. 5 and the island data can be found in the Appendix. Three load conditions are presented. Simulation A has sufficient supply to sustain the island. Simulation B has insufficient real power to supply the load. Simulation C has insufficient reactive power support to supply the island. All three load conditions are tested with communication success and failure in order to verify the contingency effectiveness of the overall system.

Fig. 5. Simulation Test Bed

#### A. Simulation A

Simulation A contains an island with greater DG supply than load. The results of the simulation are given in table I. The report generated from the code can be found in the Appendix.

Node	Voltage (p.u.)	Frequency (p.u.)
DG	1.087	1.427
ILS1	1.04058	1.427
ILS2	1.02018	1.427

TABLE I  
SIMULATION A RESULTS

The results indicate a loss of mains detection via OFP by the DG unit which initiates the islanding protection algorithm. The

islanding protection algorithm predicts that the real and reactive power support of the DG unit will be able to sufficiently supply the island. Hence, no alarm is sent to the STS and no forced load shedding occurs. Both ILS modules observe an elevated frequency. However, the ILS algorithms also predict that there is sufficient real and reactive power supply within the island. The DG shifts to autonomous mode and the system frequency can be restored. This scenario behaves in exactly the same way during a communication outage as no tripping instructions have been transmitted between the devices. This simulation has behaved as expected and no nuisance tripping has occurred.

### B. Simulation B

Simulation B contains an island with an insufficient real power supply to support the load. The results of this simulation are given in table II. The report generated from the code can be found in the Appendix.

Node	Voltage (p.u.)	Frequency (p.u.)
DG	0.948	1.397
ILS1	0.89484	1.397
ILS2	0.873	1.397

TABLE II  
SIMULATION B RESULTS

As in Simulation A, the islanding protection is triggered by OFP. The DG islanding protection detects an insufficient real power supply and an alarm is sent to the STS to request load shedding of the island. When communications are working successfully, the first ILS on the ‘trip list’, load 2, is isolated. The islanding algorithm then detects that the DG unit will now be able to sufficiently supply the island and the alarm signal is stopped. The STS then interrupts the load shedding algorithm and the DG unit changes to autonomous control mode. ILS1 does not detect an insufficient reactive power supply for long enough to trip. Hence, the highest priority load continues to be supplied.

When the same situation was simulated with faulty communications, the alarm sent to the STS was not recognised. Hence, neither ILS received a trip signal from the STS. However, ILS1 and ILS2 both detected an insufficient supply to the island. ILS2 tripped before ILS1 due to the time delay setting coordination of the load management scheme. Once ILS2 tripped, the anti-islanding alarm switched off and the ILS1 observed a sufficient supply within the grid. The highest priority load remained connected to the island. The DG unit shifted to autonomous control and satisfactory island conditions were realised.

### C. Simulation C

Simulation C contains an island with an insufficient reactive power supply to support the load. The results of this simulation are given in table III. The report generated from the code can be found in the Appendix.

Node	Voltage (p.u.)	Frequency (p.u.)
DG	1.087	1.997
ILS1	1.040581	1.997
ILS2	1.019976	1.997

TABLE III  
SIMULATION C RESULTS

Once more, the LOM is originally detected by OFP. OFP has been a common element throughout the simulations as the resonant frequency of the island is unlikely to be close to nominal. An island with a high DG penetration operating at unity power factor in grid connected mode is likely to have a similar real power set point to the load of the island, which suggests that voltage deviations may not be significant. When communications are healthy, the DG unit predicts that the reactive power capabilities of that DG will not meet the requirements of the island. Subsequently, the DG islanding protection signals an alarm to the STS and ILS2 is tripped. At this point, the islanding protection calculates that the DG shall be able to adequately supply the island, and the trip list sequence of the STS is terminated. Similarly, ILS1 does not observe a power deficit and does not trip. Hence, the load management scheme has operated as expected and the DG unit can supply the island with an acceptable voltage and frequency.

When communications systems are faulty, the alarm signal sent by the DG unit is not received by the STS and the trip list sequence is not triggered. However, ILS2 determined an insufficient reactive power supply and tripped. The DG unit’s alarm signal ceased and the DG changed to autonomous mode. ILS1 did not detect an insufficient reactive power support for enough time to trip. Hence, the load management scheme has operated as expected for all scenarios.

## IV. CONCLUSIONS

A new method for island load management has been presented and simulations have verified that, on a theoretical level, such a methodology could be utilised within the Microgrid concept. Contingencies for communications and ILS failure have been provided and supply to higher priority loads has been maintained where possible. DG islanding protection systems have successfully been able to discriminate between the need for anti-islanding protection and autonomous modes of operation. ILS modules were able to detect real and reactive supply deficits independently and trip in an appropriate manner. Frequency shift was shown to be the most likely form of LOM detection. Real power matching is more likely than reactive power matching in Microgrids of high DG penetration where DG operates at unity power factor during grid connected mode. Future work will involve investigating the voltage and frequency response of an ILS module’s PCC in the presence of non-linear loads as well as determining adequate time delay settings for an island with various types of DG. This work will



involve transient response modelling of DG units and voltage and frequency dependent loads.

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## APPENDIX

### Island Data

All quantitative values are in per unit.

Branch	Resistance (p.u.)	Inductance (p.u.)
Line 1	0.05	0.002
Line 2	0.05	0.002

TABLE IV  
IMPEDANCE DATA

Sim.	Node	P	Ql	Qc	$P_{ILS}$	$Q_{lILS}$
A	DG	1	0	0	N/A	N/A
A	Load1	0.5	0.1	0.05	0.6	0.15
A	Load2	0.4	0.05	0.025	1	0.2
B	DG	1	0	0	N/A	N/A
B	Load1	0.7	0.1	0.05	0.9	0.15
B	Load2	0.5	0.05	0.025	1.4	0.2
C	DG	1	0	0	N/A	N/A
C	Load1	0.5	0.1	0.02	0.7	0.15
C	Load2	0.4	0.05	0.025	1	0.35

TABLE V  
DG AND ILS DATA

### Reports

$Q_{cmax}$	0.075 p.u.
$P_{max}$	1 p.u.
$Q_{max}(P > 0.9)$	0.2 p.u.
Trip list	[ILS2, ILS1]

TABLE VI  
OTHER SYSTEM DATA

### A. Simulation A Report

#### 1. Healthy Communications:

Vdg = 1.087000  
VILS1 = 1.040583  
VILS2 = 1.020180  
W = 1.427000 Running islanding protection...  
Islanding protection detects over frequency.  
No Alarm.  
DG switched to autonomous Mode.  
COMS healthy  
Running ILS 2 algorithm...  
No ILS 2 trip  
Running ILS 1 algorithm...  
No ILS 1 trip.  
Complete.

#### 2. Faulty Communications:

Vdg = 1.087000  
VILS1 = 1.040583  
VILS2 = 1.020180  
W = 1.427000  
Running islanding protection...  
Islanding protection detects over frequency.  
No Alarm.  
DG switched to autonomous Mode.  
COMS down!  
Running ILS 2 algorithm...  
No ILS 2 trip  
Running ILS 1 algorithm...  
No ILS 1 trip.  
Complete.

### B. Simulation B Report

#### 1. Healthy Communications:

Vdg = 0.948000  
VILS1 = 0.894843  
VILS2 = 0.873015  
W = 1.397000  
Running islanding protection...  
Islanding protection detects over frequency.  
P insufficient - Alarm activated.  
COMS healthy  
STS Trips ILS 2!  
Resimulating...  
Vdg = 1.216000

VILS1 = 1.174881  
 W = 1.428000  
 Running islanding protection...  
 Islanding protection detects over voltage.  
 Islanding protection detects over frequency.  
 No Alarm.  
 DG switched to autonomous Mode.  
 Running ILS 1 algorithm...  
 No ILS 1 trip.  
 No more trips.

## 2. Faulty Communications:

Vdg = 0.948000  
 VILS1 = 0.894843  
 VILS2 = 0.873015  
 W = 1.397000  
 Running islanding protection...  
 Islanding protection detects over frequency.  
 P insufficient - Alarm activated.  
 COMS down!  
 Running ILS 2 algorithm...  
 P insufficient - Trip ILS 2!  
 Resimulating...  
 Vdg = 1.216000  
 VILS1 = 1.174881  
 W = 1.428000  
 Running islanding protection...  
 Islanding protection detects over voltage.  
 Islanding protection detects over frequency.  
 No Alarm.  
 DG switched to autonomous Mode.  
 Running ILS 1 algorithm...  
 No ILS 1 trip.  
 No more trips.

## C. Simulation C Report

### 1. Healthy Communications:

Vdg = 1.087000  
 VILS1 = 1.040581  
 VILS2 = 1.019976  
 W = 1.997000  
 Running islanding protection...  
 Islanding protection detects over frequency.  
 Q insufficient - Alarm activated.  
 COMS healthy  
 STS Trips ILS 2!  
 Resimulating...  
 Vdg = 1.432000  
 VILS1 = 1.397074  
 W = 1.421000  
 Running islanding protection...  
 Islanding protection detects over voltage.  
 Islanding protection detects over frequency.

No Alarm.  
 DG switched to autonomous Mode.  
 Running ILS 1 algorithm...  
 No ILS 1 trip.  
 No more trips.

### 2. Faulty Communications:

Vdg = 1.087000  
 VILS1 = 1.040581  
 VILS2 = 1.019976  
 W = 1.997000  
 Running islanding protection...  
 Islanding protection detects over frequency.  
 Q insufficient - Alarm activated.  
 COMS down!  
 Running ILS 2 algorithm...  
 Q insufficient - Trip ILS 2!  
 Resimulating...  
 Vdg = 1.432000  
 VILS1 = 1.397074  
 W = 1.421000  
 Running islanding protection...  
 Islanding protection detects over voltage.  
 Islanding protection detects over frequency.  
 No Alarm.  
 DG switched to autonomous Mode.  
 Running ILS 1 algorithm...  
 No ILS 1 trip.  
 No more trips.